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THE ESSEX PROGRAM: A STUDY OF THE EFFECTS OF UNDERGROUND LOW-YI--ETC(U)
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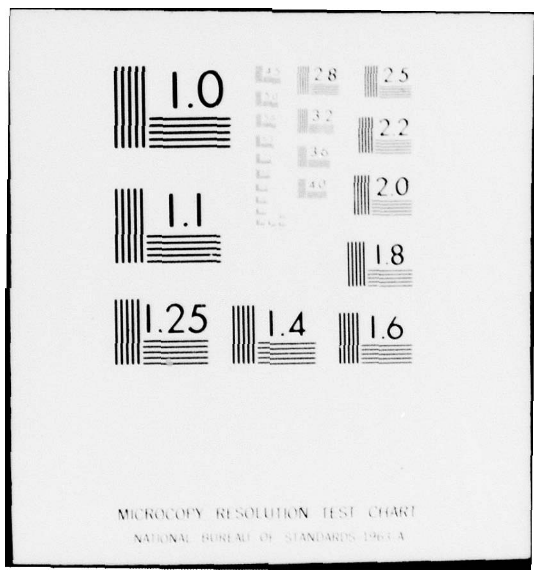
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6 THE ESSEX PROGRAM: A STUDY OF THE EFFECTS OF UNDERGROUND LOW-YIELD NUCLEAR WEAPONS EMPLOYED IN A TACTICAL WARFARE SCENARIO (U)

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The possibility of a massive, all-out invasion of Western Europe by Warsaw-Pact forces has made it necessary for the NATO Alliance to prepare for such an eventuality and to develop innovative and effective countermeasures. The initial effort of the NATO forces would be aimed at slowing the enemy's rate of advance, thus buying valuable time in which the NATO forces could mobilize and launch a telling and successful counteroffensive.

One very practical way to slow the enemy's rate of advance would be to deny him the mobility and maneuver options he needs for his armor and mechanized units, particularly along likely invasion corridors. To effect such a denial, the so-called "barrier to mobility" (BATM) concept was introduced late in the decade of the sixties. The concept involves the use of conventional or nuclear underground explosions to produce craters of sufficient size to form a viable obstacle or BATM. The low-yield atomic demolition munition (ADM) was envisioned as the nuclear energy source for producing such craters, while large quantities of conventional explosives could provide a viable alternative as to the explosive type.

In about 1973, a requirement to study the effect of low-yield nuclear explosions on various tactical-type targets was introduced. It was envisioned that such targets, at ranges up to a few hundred kilometers beyond the forward edge of the battle area (FEBA), could be attacked by an aerial- or missile-delivered warhead, i.e., a tactical earth-penetrating warhead (TEPW). It was envisioned that such a warhead would penetrate to depths below the ground surface sufficient to optimize those weapons effects needed to damage or destroy a given target or target complex.

The specific purpose of the ESSEX (Effects of Subsurface

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Explosions) Program was to study the effects of low-yield nuclear weapons, the kind envisioned for use in both the BATM and TEPW applications. In essence, the research was aimed at refining the employment doctrine for the ADM and at developing a sufficient data base from which employment doctrines for the TEPW could be formulated.

PROGRAM OBJECTIVES

Major objectives of the ESSEX Program were as follows: (a) develop a means of simulating, with high explosives, the mechanical effects of low-yield nuclear explosions that occur at various depths of burst (DOB), for various stemming conditions, and for various geologies; (b) develop a means of simulating radioactive fallout and of predicting such fallout using a nonradioactive source; (c) assess the barrier effectiveness of craters formed by low-yield nuclear weapons; (d) identify those test geometries that minimize collateral damage without degrading to an objectionable degree the primary effects; and (e) determine the vulnerability of generic classes of targets to the free-field explosion effects (primarily cratering, ground shock/motion, and debris impact). The calculational and experimental programs have provided a data/knowledge base sufficient to develop quantitative conclusions relative to some of the objectives, and definable trends relative to the others.

APPROACH

Simulation of Mechanical Effects. In the ESSEX Program, high explosives (HE) were used to simulate nuclear explosives (NE). In the simulation, two cratering, ground-motion type calculations were conducted, one for NE and one for HE. The NE calculation considered the expansion of the nuclear source through an appropriate equation of state (EOS); this calculation served as input to a medium response calculation which used a field-developed EOS for the host material. The output of the two-phased calculation was a predicted crater profile, predicted stress levels, predicted particle velocities, and a predicted kinetic energy field.

A similar calculation was made for the HE case except that an HE source EOS was used. The NE and HE calculations were then compared, and adjustments were made in the HE yield until the cratering and kinetic energy fields at a given range were in agreement. Thus, proper simulation was tagged to a duplication of crater geometry and a duplication in the ground shock and kinetic energy fields.

Radioactive Fallout Simulation. The fallout of radioactive debris (residual fallout) was simulated by internal seeding of an HE charge using iridium-coated sand particles having a density of about 2.6 gm/cm^3 and diameters smaller than 175 microns, the latter being an appropriate size representation of actual nuclear fallout

particles [1]*.

The HE explosive used in the ESSEX Program was nitromethane, a liquid explosive having properties very similar to TNT. The iridium-coated quartz particles (10 percent of the total charge weight) were added to the nitromethane (87 percent of the total charge weight). The mixture was then stirred while adding a gelling agent (3 percent of the total charge weight). Stirring was continued until the mixture was sufficiently stiff to hold the quartz particles in suspension. Upon detonation, the particles were lofted by the venting phenomena, were carried by the winds, and eventually fell into an area where numerous sampling trays caught the fallout. Appropriate subsamples from each tray were then neutron irradiated, and the radioactivity of each subsample was determined by gamma ray spectrometry. The actual irridium content was determined by its characteristic 0.316-Mev gamma ray. Using this method, it was possible to contour the deposition pattern and through appropriate factors to relate the iridium fallout to the dose rates expected for a nuclear event of roughly equivalent yield.

TEST PROGRAM

The experimental program of ESSEX consisted of nine detonations, each with a nominal yield of 10 tons TNT equivalent. A complete listing of the shots is shown in Table 1; the various experimental programs, conducted on each of the shots, are listed in Table 2. All shots were fired in the Peason Ridge Area of the Fort Polk Military Reservation near Leesville, Louisiana. The near-surface geology was typically sandy-clays and clayey-sands; at one site (12MU), a fairly competent rock layer (about 6 metres thick) was present at a depth of about 2 metres. A major target-response program was conducted in conjunction with the 6MPS Event.

RESULTS OF THE PHENOMENOLOGICAL EXPERIMENTS

Cratering. Dimensions of the nine ESSEX craters are given in Table 1. Omitting the 12MU results (the 12MU Event was the shot with the 6-metre siltstone rock layer), the apparent crater depths ranged from 4 to 9 metres; the radius from 19 to 27 metres; and the volume from 4000 to 6000 cubic metres. The mean dimensions of the craters, excluding 12MU, were: depth, 5.7 metres; radius, 22.7 metres; and volume, 4850 cubic metres. The overall variations reflect a data spread of roughly ±50 percent for depth and ±20 percent for radius and volume. These ranges reflect the variations associated with the insitu geological differences, the variations in the depth of burst, and the variations in the stemming of the charge emplacement

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TABLE 1. LISTING OF ESSEX SHOTS ALONG WITH CRATER DIMENSIONS

Shot	Yield, tons	Apparent Crater Dimensions Radius, m	Depth, m	Volume, m^3	True Crater Radius, m
3MS	11.5	21.5	4.9	4290	24.0
3MU	9.0	20.6	4.6	4400	25.0
6MS	10.0	26.2	4.6	6050	33.5
6MPS	10.0	21.8	5.0	5400	27.0
6MWS	10.0	20.6	9.3	5530	22.0
6MU	8.0	23.6	5.2	5010	27.4
12MS	10.0	18.8	8.5	4750	22.1
12MPS	10.0	26.9	3.7	5360	--
12MU	8.0	14.4	4.0	1200	19.0

TABLE 2. TECHNICAL PROGRAMS OF ESSEX

Technical Program	Title
1	Cratering, Ejecta, and Barrier Effectiveness
2	Ground Shock/Motion Measurements
3	Airblast Measurements
4	Technical Photography
5	Radiation Simulation
6	Detonation Physics
7	Code Calculations for Simulation Design
8	Geologic Exploration and Equation of State Studies
9	Construction and Support

hole.

All nine craters constituted a BATM for the following vehicles: an M60 tank, an M113 armored personnel carrier, and the M175 1-1/4-ton wheeled cargo vehicle. The relative size of the ESSEX craters compared to those that would result from a 1-KT nuclear yield is shown in Figure 1; the 1-KT crater provides a BATM roughly 3.5 times larger than the one associated with the 10-ton HE events.

Ejecta. For the nine ESSEX events, the continuous ejecta field was generally confined to within a range equivalent to 3 apparent crater radii. The thickness of the continuous ejecta blanket at its thickest point was about 1/5 of the crater depth.

The maximum range to which ejecta fragments (clods) were thrown ranged from ~300 metres for the 12M Events to ~800 metres for the 3M Events. Scaled maximum ejecta range (SR_{max}) as a function of scaled DOB (SDOB) is shown in Figure 2. Included in the data set were a number of large HE shots plus several nuclear events. The data are empirically defined as a bilinear upper bound of the data envelope. Appropriate equations for these lines are given, and from them, expected maximum ejecta range can be calculated; however, yields larger than about 1000 tons (TNT equivalent) should not be used.

Ground Shock/Motion. Shock and motion measurements, primarily stress and particle velocity, were made generally at the same depth as the shot, i.e., at shot horizon, and at locations near the ground surface. At the shot horizon, which was generally in a wet soil, the shock propagation velocities for the nine events ranged from 1400 to 2000 metres/sec. In the dryer soil layers (layers well above the water table), the propagation velocity was in the range of 400 metres/sec.

Stress levels and particle velocities as a function of range are shown in Figures 3 and 4, respectively, for gages emplaced at shot depth (wet soil). Stress amplitudes in a significantly dryer soil but still quite moist (the 6MPS Event) were lower than those shown in Figure 3 by a factor of 30 to 40. Excluding the 6MPS results, the particle velocities for the 6M DOB's events were approximately three-fourths those at the 12M DOB; and those at the 3M DOB's were about one-third those at the 12M DOB's. Generally, the stemmed shots tend to define the upper bound of the data and the unstemmed data the lower bound.

Airblast. Results of the airblast measurements close-in and far-out are shown in Figures 5 and 6, respectively. The shallow-buried, unstemmed shots form the upper bound of the observed data and the more deeply buried, stemmed shots form the lower bound. For the long-range airblast, the 3MU overpressure curve is higher than the 12MS curve roughly by a factor of 30. Damage to typical aboveground military targets is not expected to be significant if the overpressure

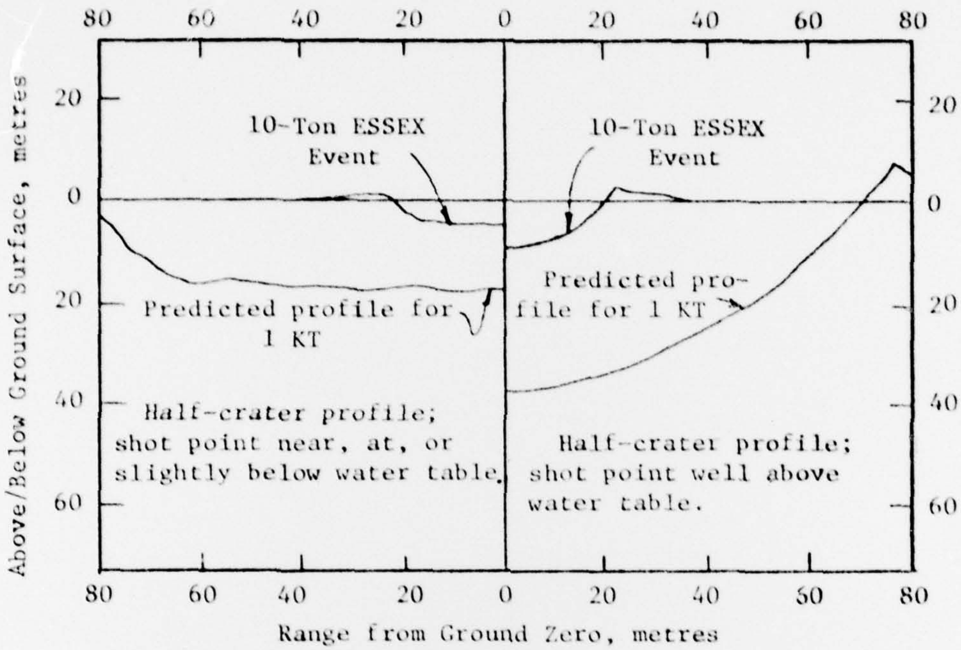

FIGURE 1 Comparison of ESSEX-type crater with the predicted crater for a 1 KT yield at the same scaled depth of burst (20 metres).

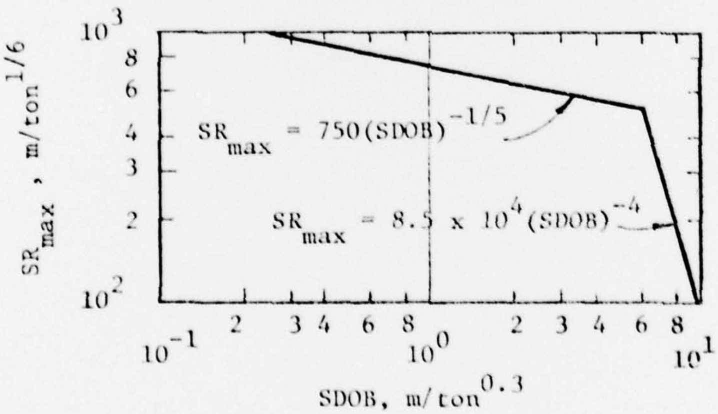

FIGURE 2 Scaled maximum ejecta range as a function of scaled depth of burst.

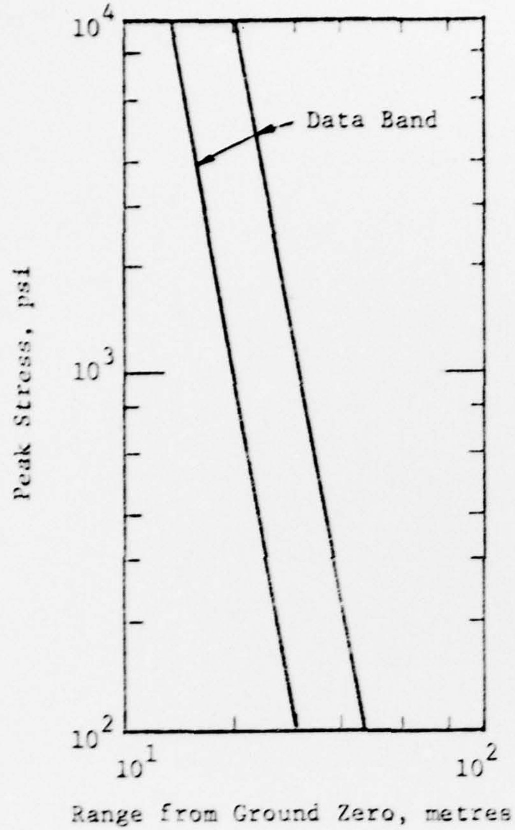

FIGURE 3 Direct induced peak stress as a function of range from ground zero.

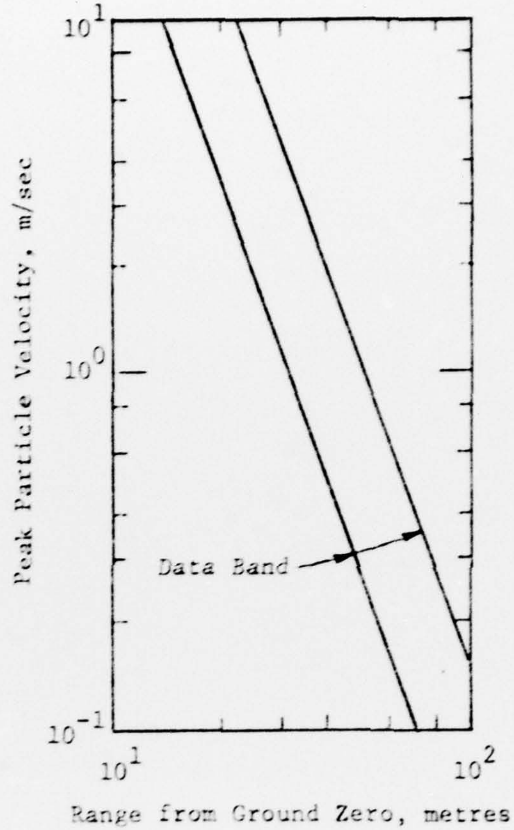

FIGURE 4 Peak particle velocity as a function of range from ground zero.

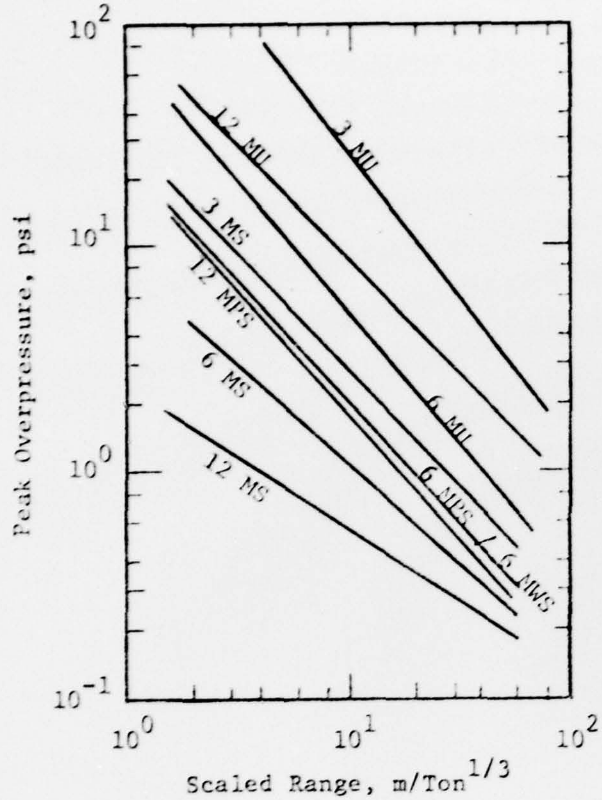

FIGURE 5 Results of close-in airblast measurements.

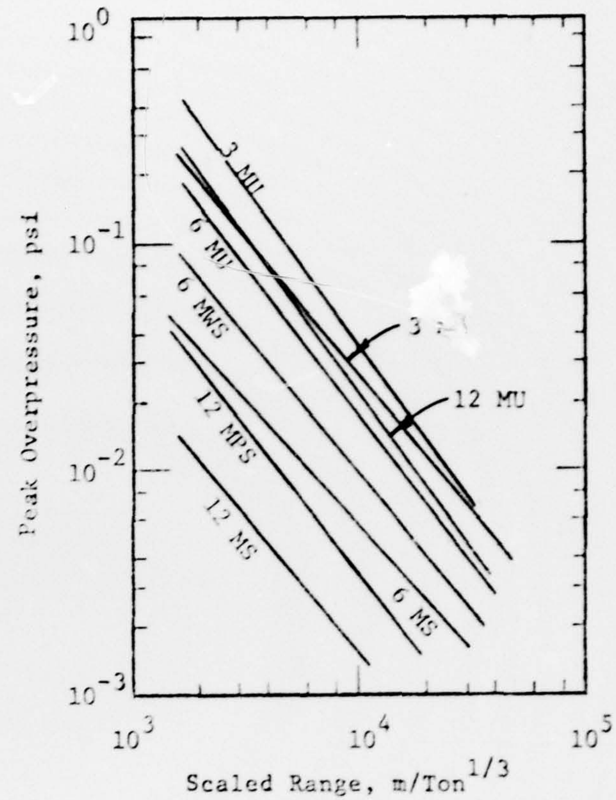

FIGURE 6 Results of far-out airblast measurements.

is less than about 0.03 psi (2 millibars).

Radiation Simulation. The highly significant implications of the radiation simulation experiments, conducted on eight of the nine ESSEX Events, are shown in Figures 7 and 8. The vent fractions* common to the ESSEX shots are much lower, generally an order of magnitude lower, than shots which occurred in dry soils. Prior to ESSEX, an increase in the vent fraction had been predicted for detonations in wet soil; obviously the ESSEX results show just the opposite. Significance of the lower vent fraction means that the dose rates beyond the limit of the continuous ejecta will be less than values obtained from current prediction methods by a factor of 10 or more.

Figure 8 graphically shows the 150 rad envelope as predicted by current state of the art codes and the 150 rad envelope predicted by the NCG method [2] and by ESSEX. As is evident, the residual radiation poses much less of a problem than originally thought assuming the results of the ESSEX simulation technique are valid. An ESSEX-type simulation shot has been proposed for the Nevada Test Site (NTS) to test the validity of the ESSEX results against the results of a nuclear event. Meanwhile, systems designers are cautioned not to make use of these data until the results of the NTS validation tests are available or until analytical studies now underway show the results to be valid.

STRUCTURAL RESPONSE EXPERIMENTS

Various structures, representative of likely theater targets were constructed to a scale of 1 to 3.7**. The structures were exposed to the blast and shock effects of the 6MPS Event. The structural array is shown in Figure 9. In addition, airfield runway response was evaluated on two other shots, viz., the 3MS and 12MS Events. The response of the various structures are described below.

Airfield Runways. Model airfield runways, constructed in the same manner as full-scale Warsaw Pact runways, exhibited considerable damage due to vertical displacement of the articulated slabs out to about 2 crater radii for a detonation occurring at near optimum depth for cratering. Damage due to ejecta debris, sufficient to preclude use of the runways, occurred out to about 5 crater radii. For 1 KT, these damage radii would amount to about 200 metres for damage due to uplift and displacement and about 500 metres due to ejecta debris.

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*Vent fraction is defined as that fraction of the total radiation vented that falls beyond the limits of continuous ejecta.

**At the scale of 1 to 3.7, the 10-ton events of ESSEX model a nuclear detonation of about 1 KT.

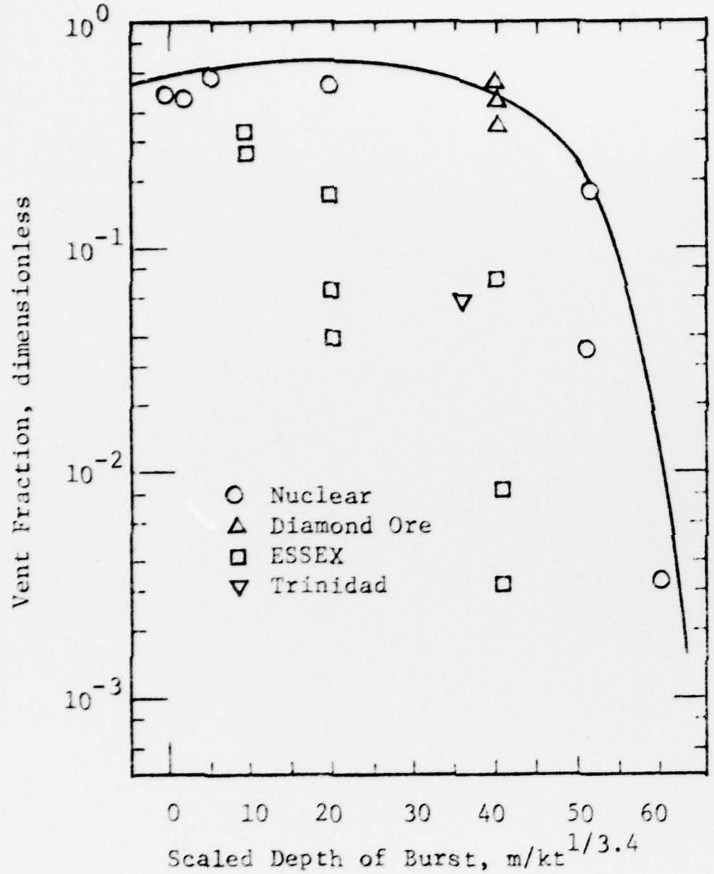


FIGURE 7 Variation of vent fraction with scaled depth of burst.

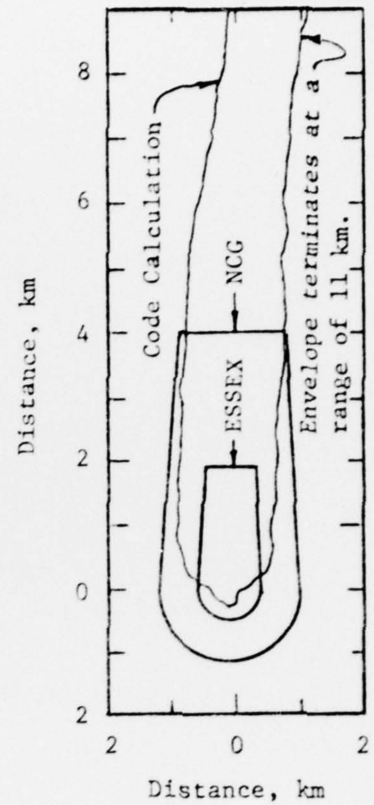
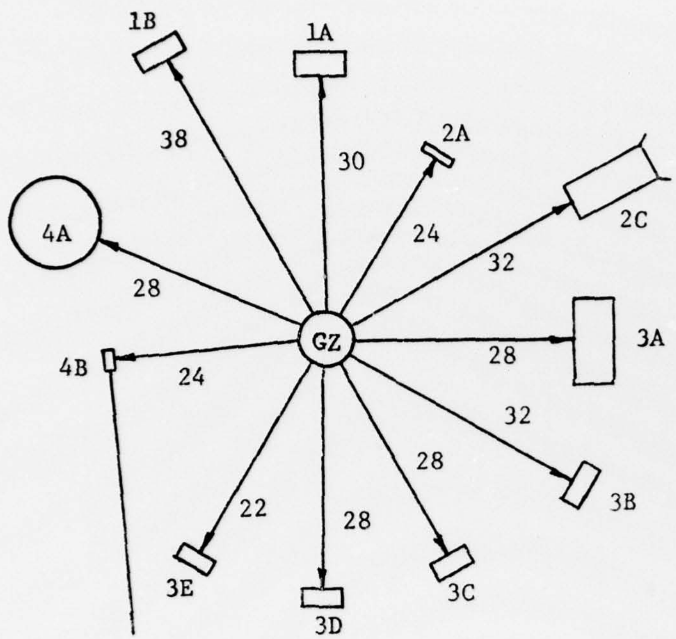


FIGURE 8 Comparison of 150 rad at 50 hours.



1 Aircraft Shelter
- 1A Structure 1
- 1B Structure 2

2 Bridges
- 2A Bridge Pier on piles
- 2B Bridge Span

3 Buried Hardened Structures
- 3A Arch Structure
- 3B Rectangular Structure (L/d = 10)
- 3C Rectangular Structure (L/d = 10)
- 3D Rectangular Structure (L/d = 4)
- 3E Rectangular Structure (L/d = 4)

4 POL
- 4A Storage Tank
- 4B Pipeline

NOTE: Numbers along the various radials are distances (in metres) from ground zero (GZ) to each structure.

FIGURE 9 Structural array for the Phase 3 Event of ESSEX.

Hangarettes. The aircraft shelters exposed to the 6MPS Event were 1/3.7-scale models of earth-mounded, precast, reinforced concrete shelters made of 90-degree arch segments bolted at the crown and supported by precast strip footings. Both shelters, one at 30 metres and one at 36 metres, apparently were undamaged by either the blast or shock; however, the 30-metre shelter collapsed as a result of the ejecta fallback and the one at 36 metres was severely damaged by ejecta.

Bridging. A typical bridge, typical in the sense that it was representative of the population of bridges within the Warsaw Pact that might be targeted, was constructed at a scale of 1 to 3.7 and exposed to the effects of the 6MPS Event. The single-span bridge, consisting of one pier and an abutment, was aligned along a radial extending from ground zero (GZ); the pier was located 32 metres from GZ and the abutment was 44 metres from GZ (thus the bridge span was 12 metres).

Test results indicate that bridges will be generally undamaged from underground bursts unless a pier or abutment is within one apparent crater radius of GZ. Moreover, the test showed that ejecta fallback of the character present in the Fort Polk tests is not capable of destroying a bridge span even when the 10-ton results are scaled to 1 KT.

Reinforced Concrete Box Structures. Four rectangular box structures, buried 6 decimetres and having interior dimensions of 1.2 metres high, 1.2 metres wide, and 5.5 metres long, were exposed to the effects of the 6MPS Event. Two structures had wall, roof, and floor thicknesses of 12 cm [roof span-to-thickness ratio (RSTR) was 10] while the other two structures had wall, roof, and floor thicknesses of 30 cm (RSTR was 4). The structures were placed at ranges of 22 metres (RSTR=4), 28 metres (RSTR=4), 28 metres (RSTR=10), and 32 metres (RSTR=10).

Preshot predictions, made from two-D finite element codes, indicated structural damage for all structures based on the stress-time histories observed from other ESSEX shots. As pointed out earlier, the stress levels common to the 6MPS Event were lower (by a factor of 30 to 40) than anticipated and consequently no structural damage occurred to any of the structures. They were however severely displaced, moving as a rigid body (the structures were somewhat less massive than the soil they displaced). Had personnel been inside the structures at the 22- and 28-metre ranges, they undoubtedly would have sustained serious injury. Equipment inside these same structures likely would have been damaged and perhaps rendered inoperable.

Reinforced Concrete Arch. A circular arch, buried 6 decimetres with an interior radius of 2.1 metres, thickness of 28 cm, and length of 7.5 metres, was exposed also to the 6MPS Event. The arch

was placed broadside to the event at a range of 28 metres. As was the case with the buried box structures, no structural damage was experienced by the arch. Thus, one would not expect structural damage to similar arches in such a media at a range of 1.3 crater radii or at a scaled range of 14 $m/ton^{1/3}$ (140 $m/KT^{1/3}$).

Shallow-Buried POL Tank and Pipeline. The ESSEX POL storage tank modeled a typical Warsaw Pact type tank. The model tank was fabricated with steel walls; its roof was constructed with reinforced concrete supported by steel beams and columns. Its diameter was 15.5 metres. The tank was surrounded by a circular reinforced concrete retaining wall with a walk space between the tank wall and the retaining wall. The tank was underground and covered with 12 to 15 cm of natural soil.

The tank, located with its nearest point 28 metres from GZ, was destroyed by the blast. The tank, filled with water to simulate fuel, was completely emptied by the net effect of the blast. Principal damage was caused by differential displacements associated with the mass movement of the earth material involved in the crater rim upthrust and by ejecta, which collapsed the roof of the structure.

A model POL pipeline (15 centimetres in diameter) was also exposed to the 6MPS Event and survived with but minor loss in pressurization (500 psi before the shot; 400 psi after the shot). The pipeline was oriented along a tangent to a circle 24 metres in radius and centered on GZ. The simulated pumping plant was located at the point of tangency. The pipeline was 60 metres in length. Peak transient displacements at the simulated pumping plant amounted to about 2.5 metres (horizontal) and 1.7 metres (vertical).

CONCLUSIONS

Results of the ESSEX experiments highlight the following conclusions which should not be generally applied to yields greater than a few KT.

(1) Craters resulting from yields as low as 20 tons nuclear and at scaled DOB's $\geq$ 10 $m/KT^{1/3}$ will definitely constitute a BATM if it is necessary for the vehicle to pass through the crater. Obviously, craters resulting from 1-KT yields will produce barriers of major proportions.

(2) Ejecta definitely must be considered a major cause of damage for shallow-buried structures that have only a thin earth (soil) cover if the range from GZ is less than 1.5 to 2 crater radii; for hardened aboveground structures at ranges less than 2 crater radii; and for airfield runways at ranges less than 5 crater radii.

(3) Airblast effects from underground detonations may be disregarded as a prime source of damage to hardened and/or mounded aboveground structures if located 2 or more crater radii from GZ

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provided the burst depth equals or exceeds 1.4 m/ton$^{1/3}$ (HE) and 14 m/KT$^{1/3}$ (NE).

(4) Ground shock/motion phenomena, associated with yields in the range of a few KT or less, are incapable of causing structural damage to most hardened underground structures if they are located at ranges equal to or exceeding (200 KT$^{1/3}$) metres, or about 2 crater radii. However, injury to personnel and damage to equipment inside such structures should be expected.

(5) Assuming that the radiation simulation technique of ESSEX is valid, the residual radiation levels will be much lower at reasonably large distances from GZ than current manuals predict but much higher in the crater area and its immediate environs. The higher radiation levels close-in greatly enhance the barrier effectiveness of ESSEX-type detonations by denying the enemy access to the site for a period of time on the order of days.

FUTURE PLANS

Since there is at present some differences of opinion within the radiation community as to the validity of the ESSEX simulation technique, an ESSEX-type test has been proposed for the NTS. The central purpose of this test is to compare the ESSEX radiation simulation technique with the residual radiation measurements obtained from the *TEAPOT ESS Event conducted at NTS in 1955. The ESSEX NTS* Event would be a nominal 10-ton gelled nitromethane detonation emplaced 6 metres below ground. This would roughly constitute (assuming a 2 to 1 NE/HE equivalency) a 1 to 3.7 scaled model of the TEAPOT ESS nuclear event with its nominal 1-KT yield. In addition to comparing radiation results, crater, ejecta, ground shock, airblast, cloud dynamics and overall cloud size (all properly scaled) would be compared to the TEAPOT ESS Event.

A two-volume summary report on the ESSEX Program will be published during FY 1978.

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